NEO Dynamical Properties, Orbit Determination, and Impact Prediction

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I will describe the geography of the asteroid and comet regions, together with the flux of near-Earth objects (NEOs) crossing the orbit of the Earth. Because the discovery rate and flux of Earth-crossing asteroids (ECAs) is about an order of magnitude larger than that of Earth-crossing comets (ECCs), it is the former objects that predominate in orbit determination and hazard evaluation. Newtonian or relativistic force models accurately explain the motions of ECAs, but some comets exhibit activity due to vaporizing ices that requires the use of nongravitational forces to model their observed motions.

Orbit determination begins at the moment of discovery, and orbits are refined as the observational arc lengthens. Most NEOs are discovered by virtue of their unusual sky-plane motion. Apparent magnitude and sky-plane motion provide a very rough measure of an ECA's size and distance; then parallax—even on the discovery night—can be used to certify nearby objects. As a rough rule, and when only optical astrometry is available, the accuracy of orbital elements—and hence of positional prediction—increases as the square or cube of the orbital arc length. Radar delay-Doppler measurements, hitherto available only for close Earth approachers, can improve ephemeris prediction by several orders of magnitude. For an orbit that is uncertain on the timescale of a century, a useful measure of an NEO's potential hazard to Earth is the minimum orbital intersection distance (MOID) between the NEO and the Earth and other planets. MOID is thus a measure of the closest possible planetary approach of an NEO that is not in resonant motion. Empirically, I have found that NEOs (excluding long-period and some other comets) having $MOID_{Earth} < 0.05$ AU should be regarded as potentially hazardous because MOID can change, due to planetary perturbations, by a few hundredths of an AU per century. Most NEOs for which $MOID_{Jupiter} < 1$ AU are likewise potentially hazardous. Typically (depending on discovery circumstances), $MOID_{Earth}$ and its evolution over a century can be reasonably well determined for an ECA only 10 days after discovery, thereby providing a powerful filter for discriminating NEOs requiring follow-up on the basis of their potential hazard.

Accurate long-term ephemeris and Earth-approach predictions can only be made when multi-apparition orbits are available. For ECAs and some ECCs observed at several apparitions, one can generally predict Earth approaches several centuries hence. Exceptions are asteroids like (2340) Hathor, that make close planetary approaches (during which they are gravitationally scattered) on timescales of decades, long-period comets and comets exhibiting nongravitational motions, all of which require frequent monitoring. An NEO's Earth-impact probability can be estimated on the basis of the Bayesian *a posteriori* probability density, from the six-dimensional integral of the (stochastic) orbit for the time interval of interest by using, for example, Monte Carlo modeling. The Earth-impact probability, together with the kinetic energy of impact, can then be used to derive a value of the so-called NEO hazard index, an easily understood parametrization that is being designed for public dissemination.